The PHOS Detector at ALICE

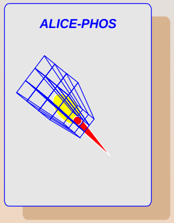
at PANIC05

in Santa Fe, NM

on October 27, 2005

— Presentation Outline —

- High-energy heavy-ion physics at LHC
- Physics via photon channel in ALICE
- PHOS detector in ALICE
- Performance evaluation with 256ch prototype
- Summary and Outlook



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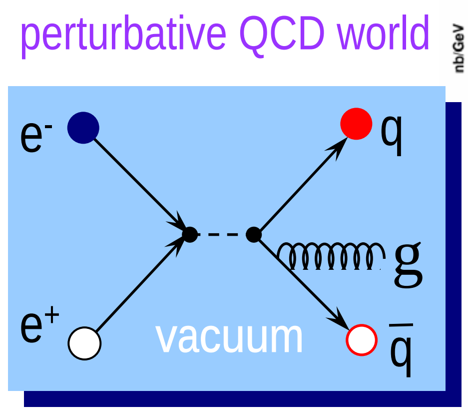
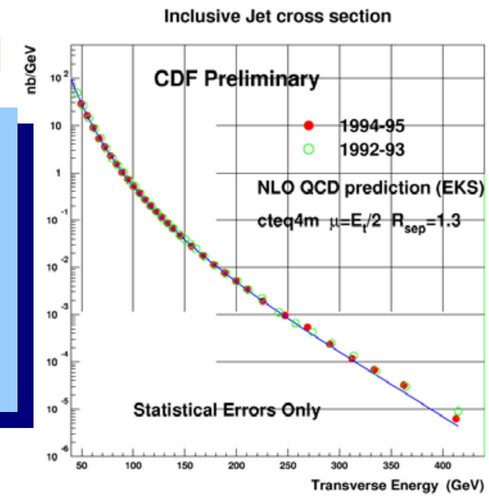
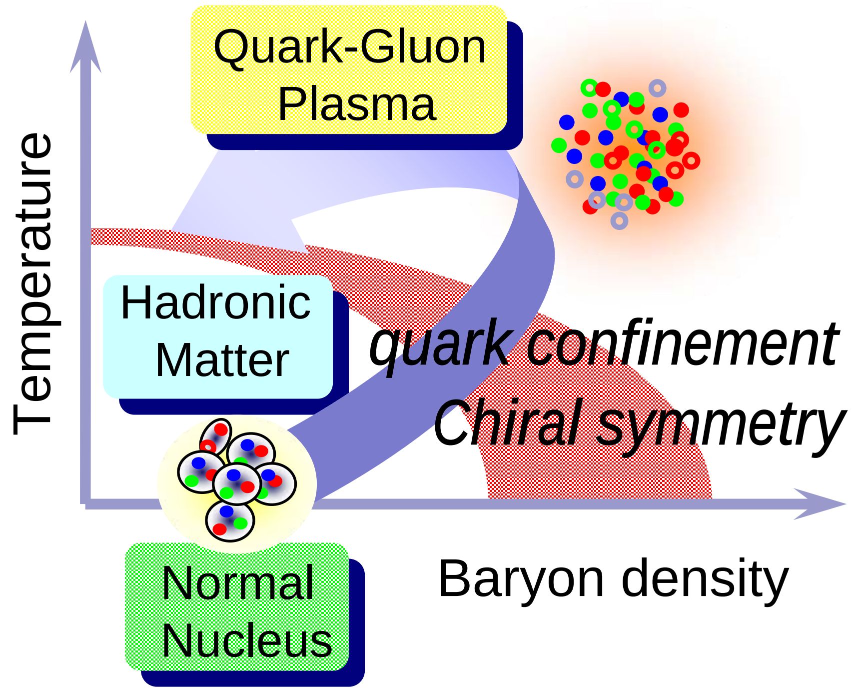
High-energy heavy-ion physics at LHC

- We know perturbative QCD works, but how about for *non-perturbative* nature?
- Many surprise come out at RHIC.
  The matter is;
  - so hot that T_{av}=300-400MeV (thermal?) photons emitted,
  - so opaque that a 20GeV π^0 stopped,
  - so dense that slow heavy quarks stopped, J/psi melted, and jet shapes modified, and
  - so strongly coupled that heavy quarks flow.
- RHIC creates ***perfect liquid*** of ε >15 GeV/fm^3 at T_{av} = 300-400 MeV.
- LHC opens a new domain of ***hard-physics*** – sensitive to early stage.
  - reproduce of earlier Universe a few μsec after Big-Bang.
  - look for what unexpected.

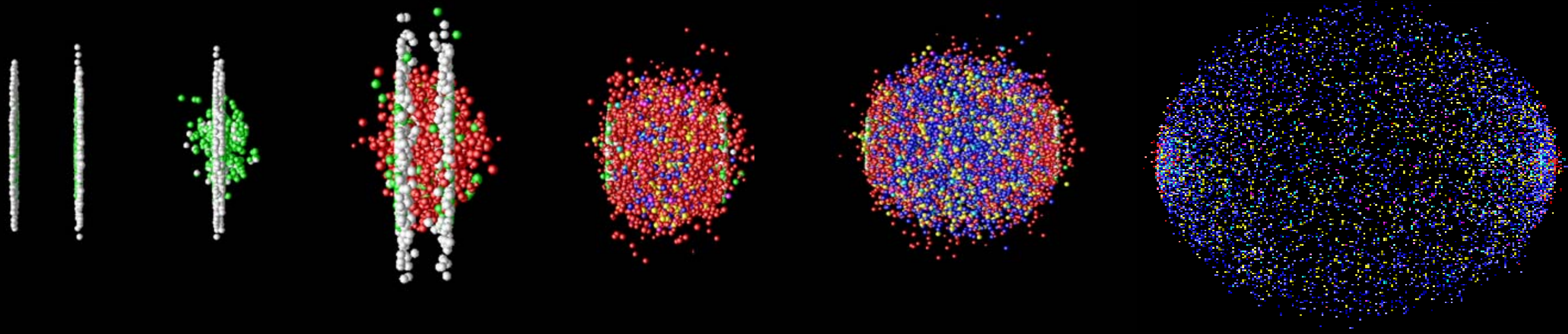






Relativistic Heavy Ion Collision

Pre-equilibrium **Thermalization** **QGP phase?** **Mixed phase** **Hadronization (Freeze-out) + Expansion**



- **Global observables:** Multiplicities, η distributions
- **Degrees of freedom as a function of T:** hadron ratios and spectra, dilepton continuum, ~~direct~~ thermal photons
- **Early state manifestation of collective effects:** elliptic flow
- **Energy loss of partons in quark gluon plasma:** jet quenching, high pt spectra, open charm and open beauty
- Deconfinement: charmonium and bottonium spectroscopy
- Chiral symmetry restoration: neutral to charged ratios, res. decays
- Fluctuation phenomena - critical behavior: event-by-event particle comp. and spectra
- Geometry of the emitting source: HBT, impact parameter via zero-degree energy flow
- pp collisions in a new energy domain

- ALICE @LHC/CERN -

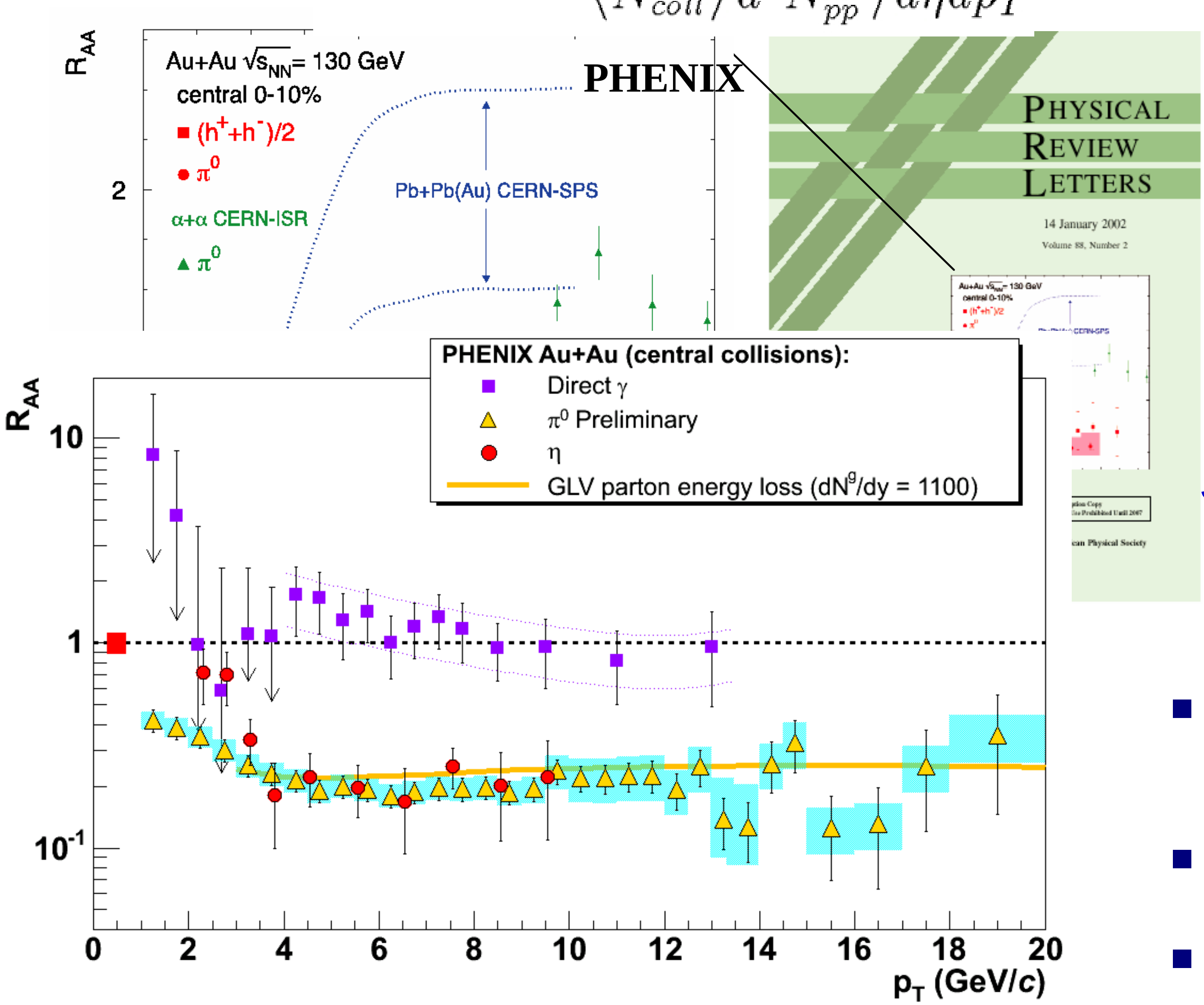
Physics via photon channels in ALICE

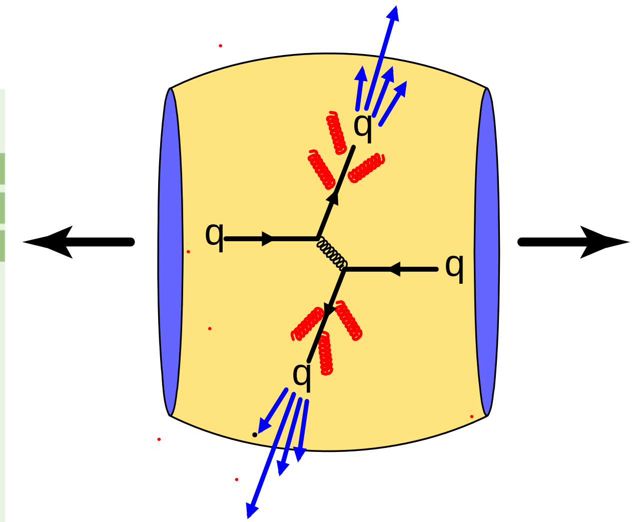
- photons in relativistic heavy ion experiments
  - vital probes of initial/hot/dense phase of collision system
    - thermal photons – ideal probe carrying information of temperature at early stage
    - direct photons - jet-tagging and ideal probe carrying information of quark scattering (pQCD) at early stage
    - HBT correlations of thermal photons – carrying information of space-time evolution of early stage
    - π^0 and η mesons - jet quenching physics and decay photon evaluation.
  - experimental virtues
    - photons and neutral mesons measured in same detector
    - particle identification to very high transverse momentum
- many interesting physics outcome at RHIC
    - more powerful tool at LHC
      - large direct photon rate up to ~100 GeV
      - high p_T physics of identified mesons up to ~100 Gev
      - jet quenching at extremely high momentum

Suppression of π^0 production in central Au-Au collisions

PHENIX Collaboration, Phys. Rev. Lett. 88 (2002) 022301

$$R_{AA}(p_T) = \frac{d^2 N_{AA}/d\eta dp_T}{\langle N_{coll}\rangle\, d^2 N_{pp}/d\eta dp_T}$$

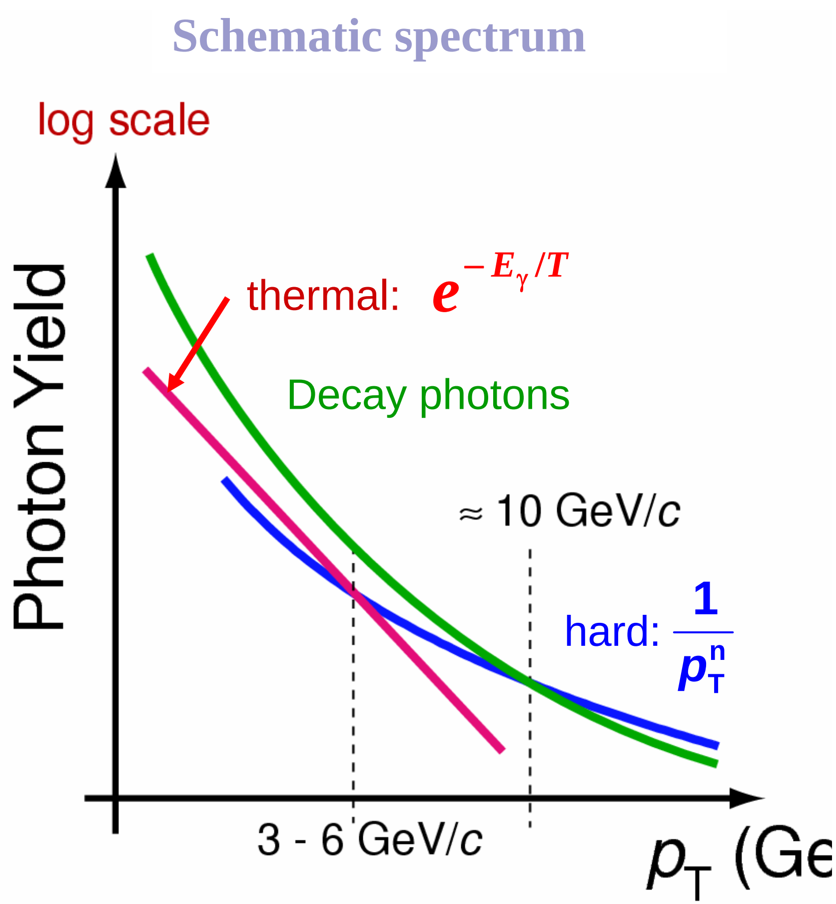




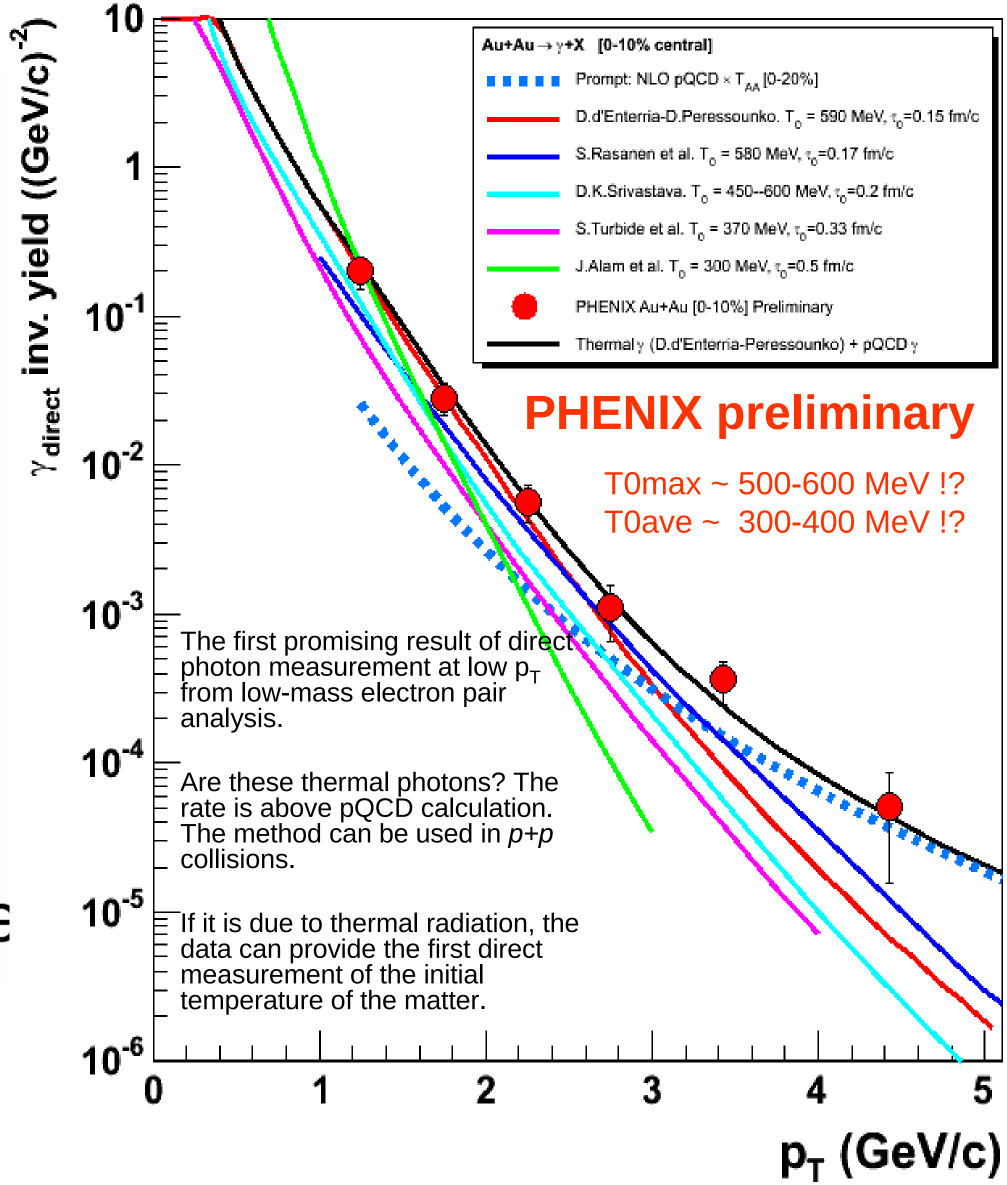
Jet quenching in hot, dense matter
X. N. Wang and M. Gyulassy,
Phys. Rev. Lett. 68 (1992) 1480

- Suppression is very strong (R_{AA}=0.2!) and flat up to 20 GeV/c
- Common suppression for π^0 and η; it is at partonic level
- ε > 15 GeV/fm^3; dN_g/dy > 1100

Photon Spectrum in central Au-Au collisions

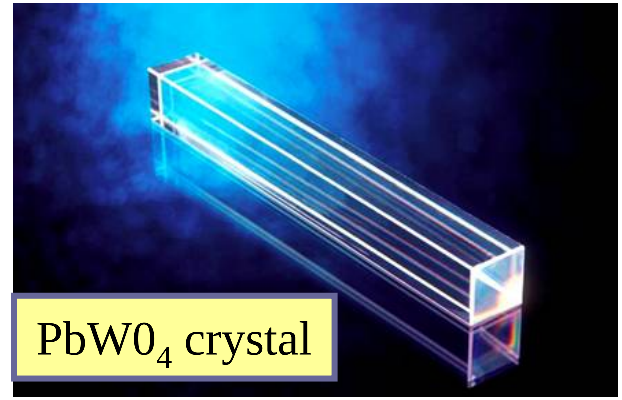


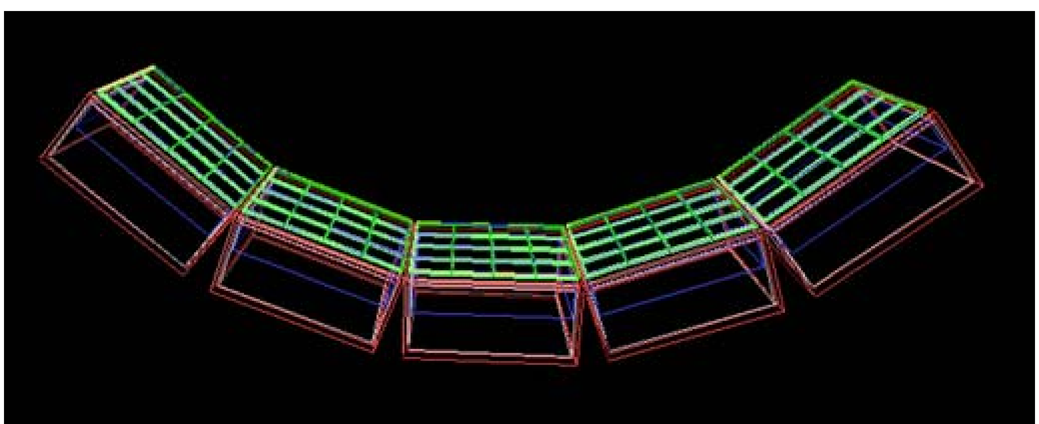
First direct photon excess seen at PHENIX

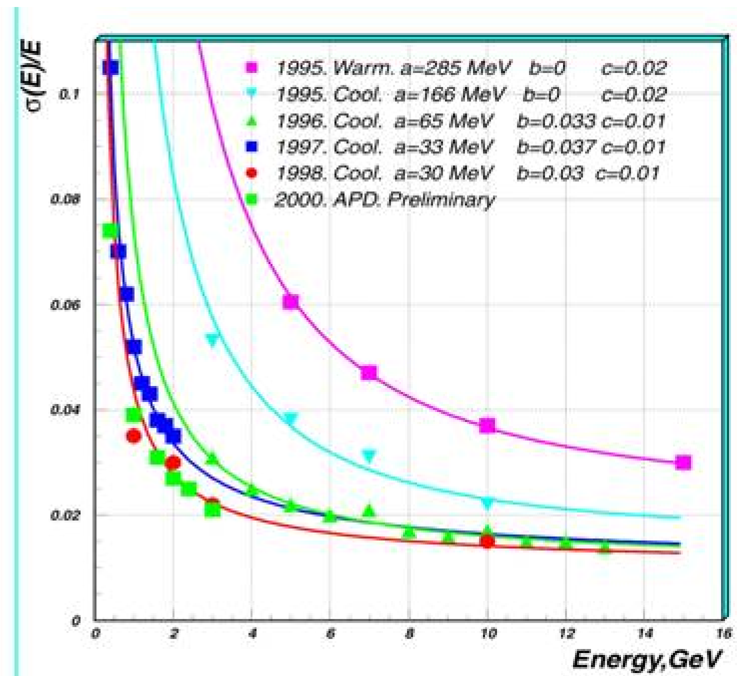


PHOS: high-granularity, high-resolution photon detector in ALICE

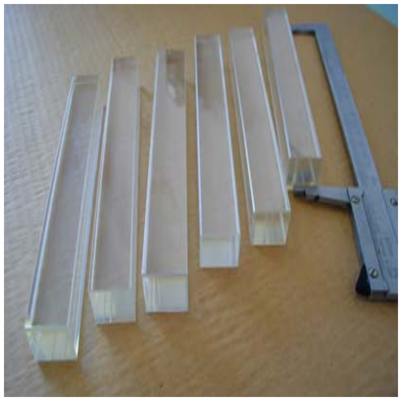
- for photons and neutral mesons measurements, and for γ-jet tagging,
- providing level-0 and level-1 trigger.
- made of $PbWO_4$ crystal of $2.2 \times 2.2 \times 18 cm^3$ ($20\ X_0$),
- readout with a APD/CSP, operated at -25 deg.
- 3,584 crystals (56x64) in a module, and
- 5 modules (17,920 crystals; 12.5 t) covering $8.7 m^2$ at 4.4 m from IP.
- covers $|\eta| < 0.12$, $\Delta\phi$=100 deg.
- achieves the energy resolution of $3\%/\sqrt{E}$ up to 100 GeV.
- resolves two particles with the smallest $R_{Moliere}$ =2.2cm.

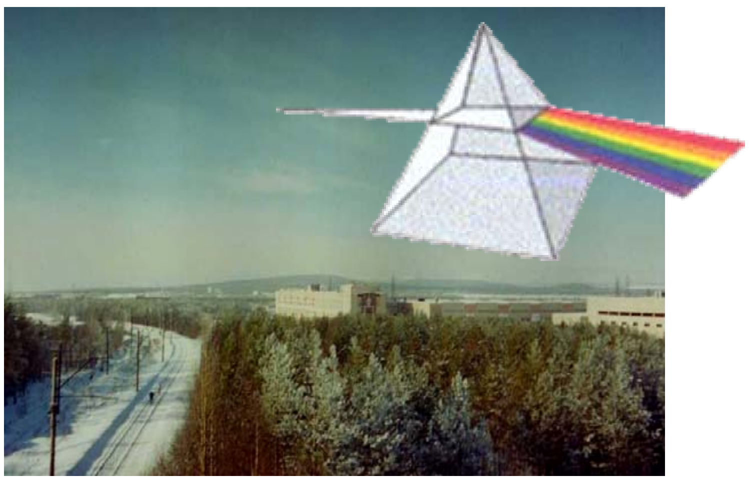






ALICE crystals from Russia



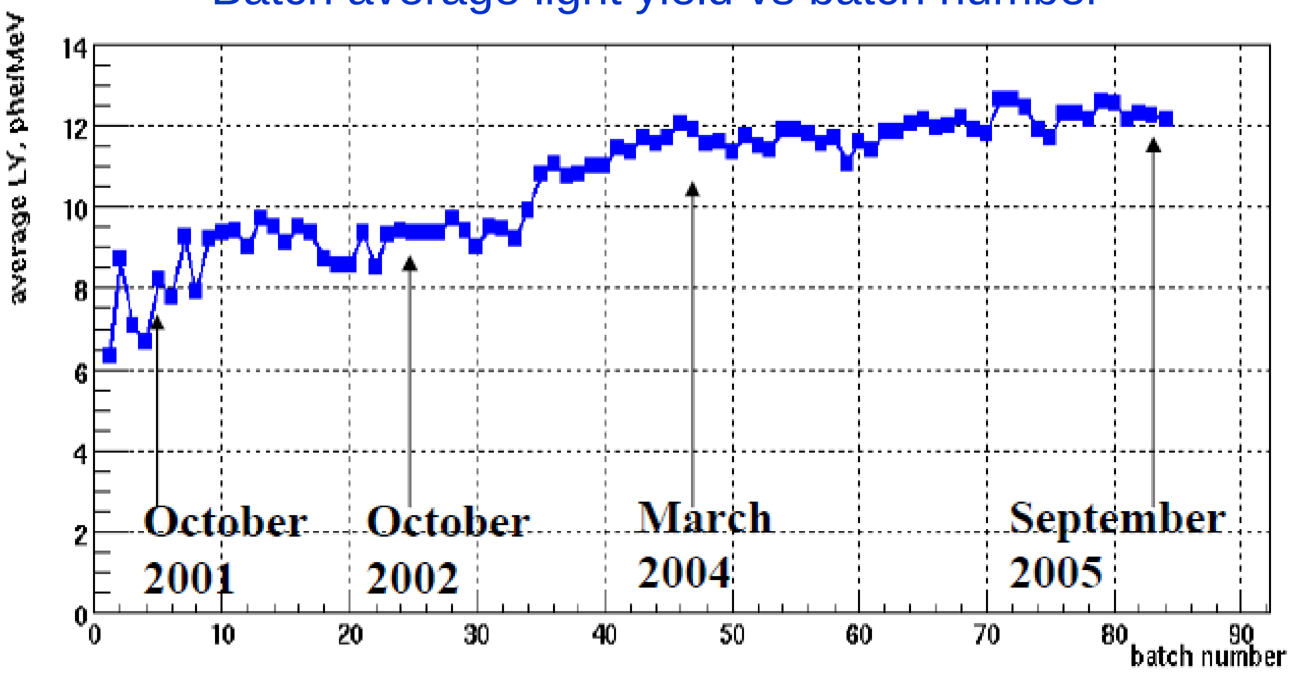


North Crystals Co. Apatity in Russia

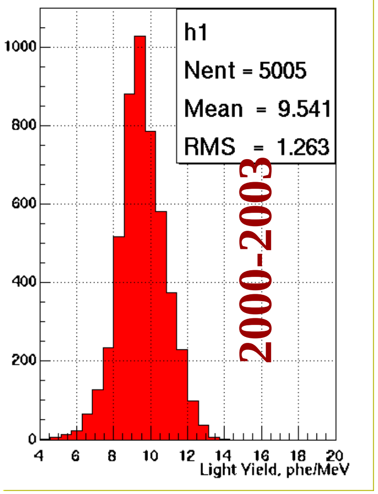
More than 9000 PWO crystals (more than 50% of the PHOS) are accepted for ALICE/PHOS as of today.

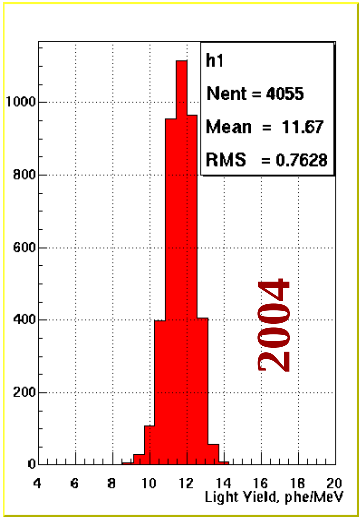
Current status of the PWO crystals production

Batch average light yield vs batch number



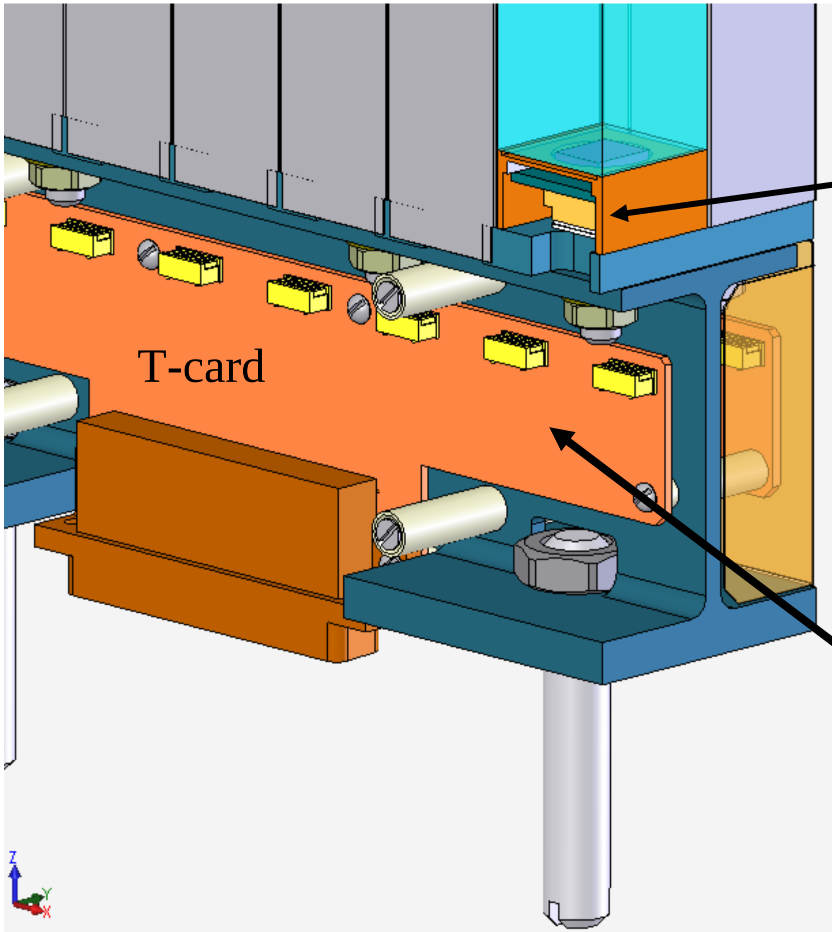
Measurement at the Kurchatov Institute



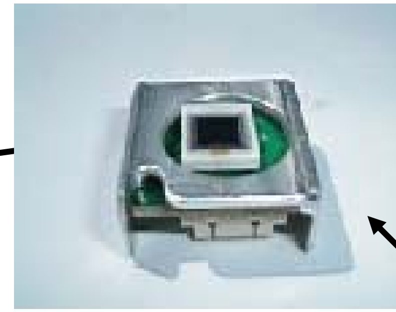


Crystal light yield distribution

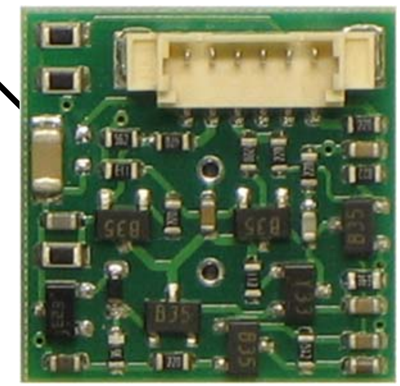
Details of cold zone electronics



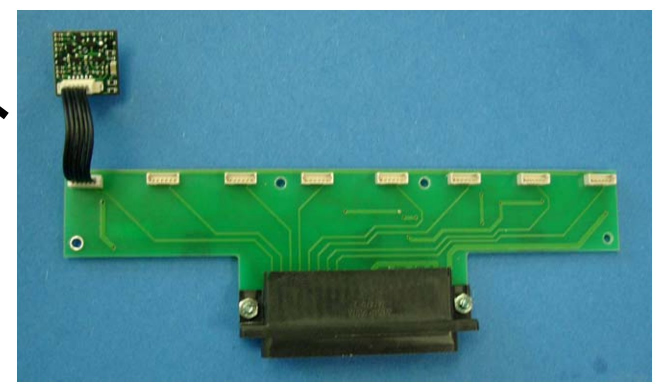
Preamplifier with APD



APD (Hamamatsu S8148) for #1 module from Norway

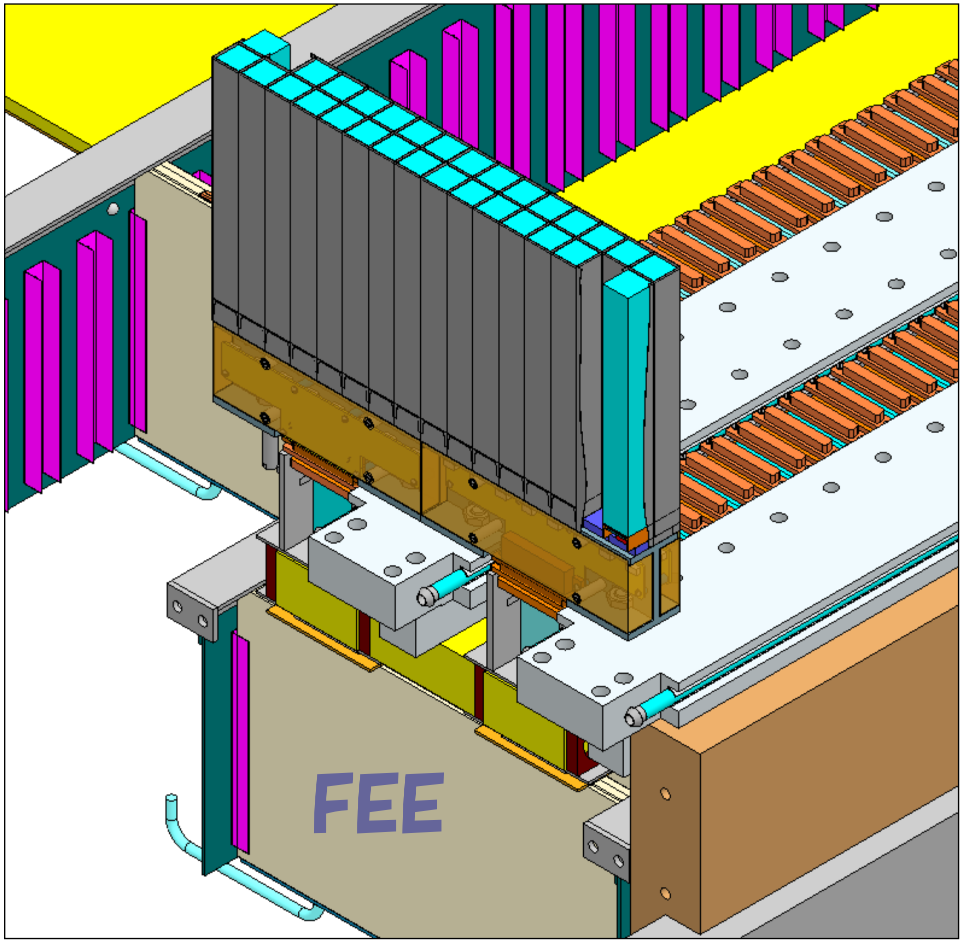


Hiroshima preamplifier (ver.3) for #1 module from Japan

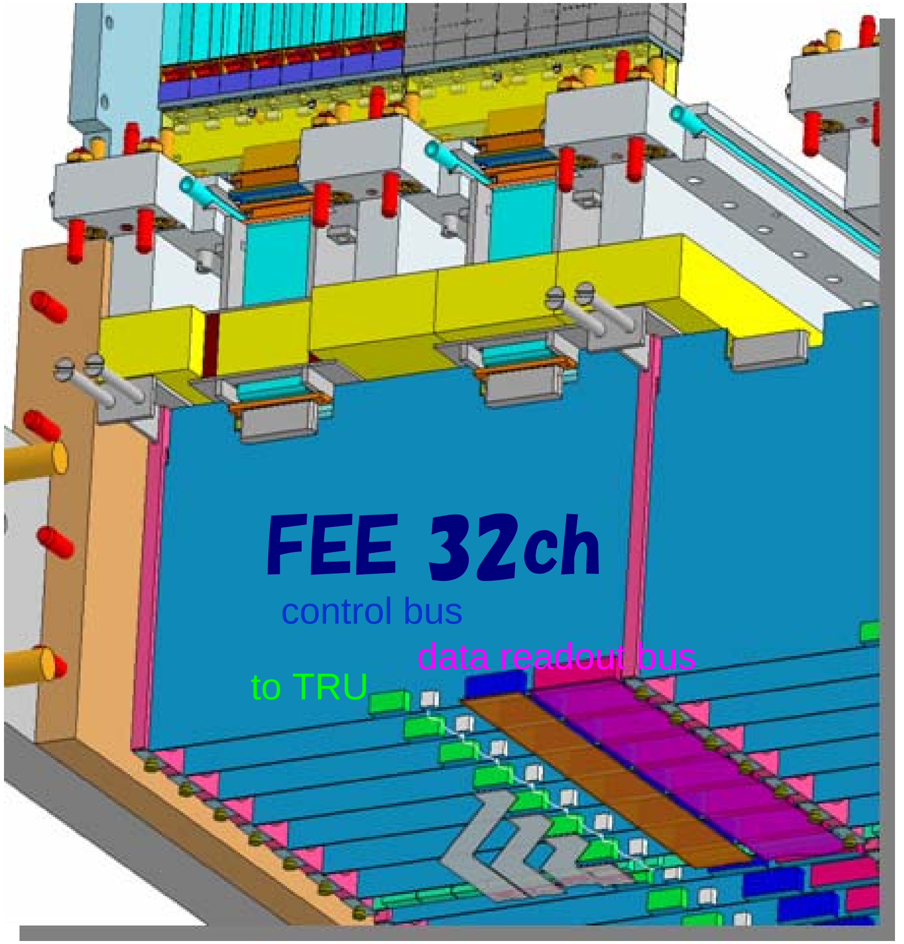


Hiroshima T-card for #1 module from Japan

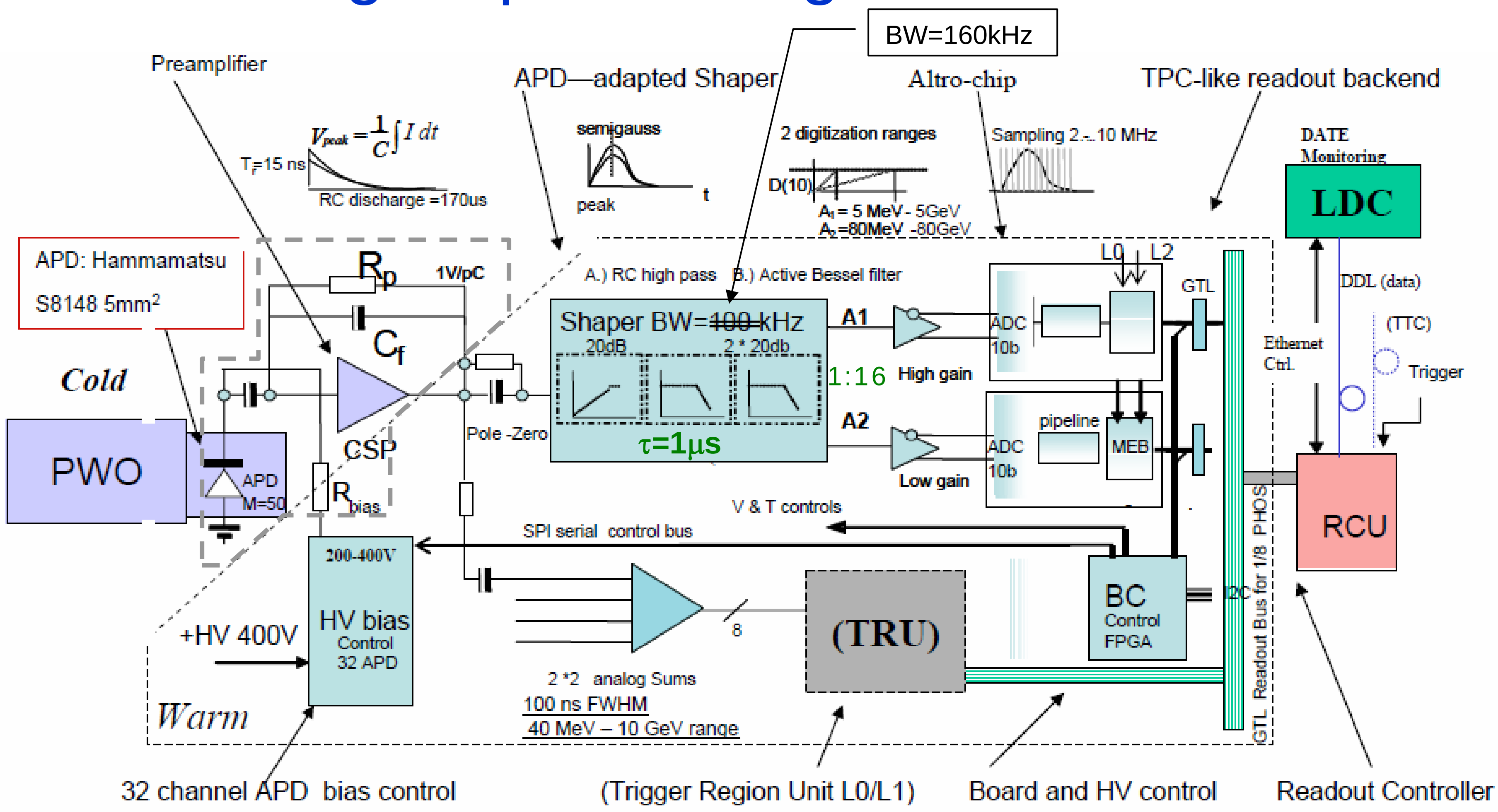
PWO 2x16=32 ch. arrays in the "cold" volume and PHOS FEE boards in the 'worm' volume of the module



Electronics 1 PHOS module:
112*FEE / 8*TRU / 3584*CSP+APD

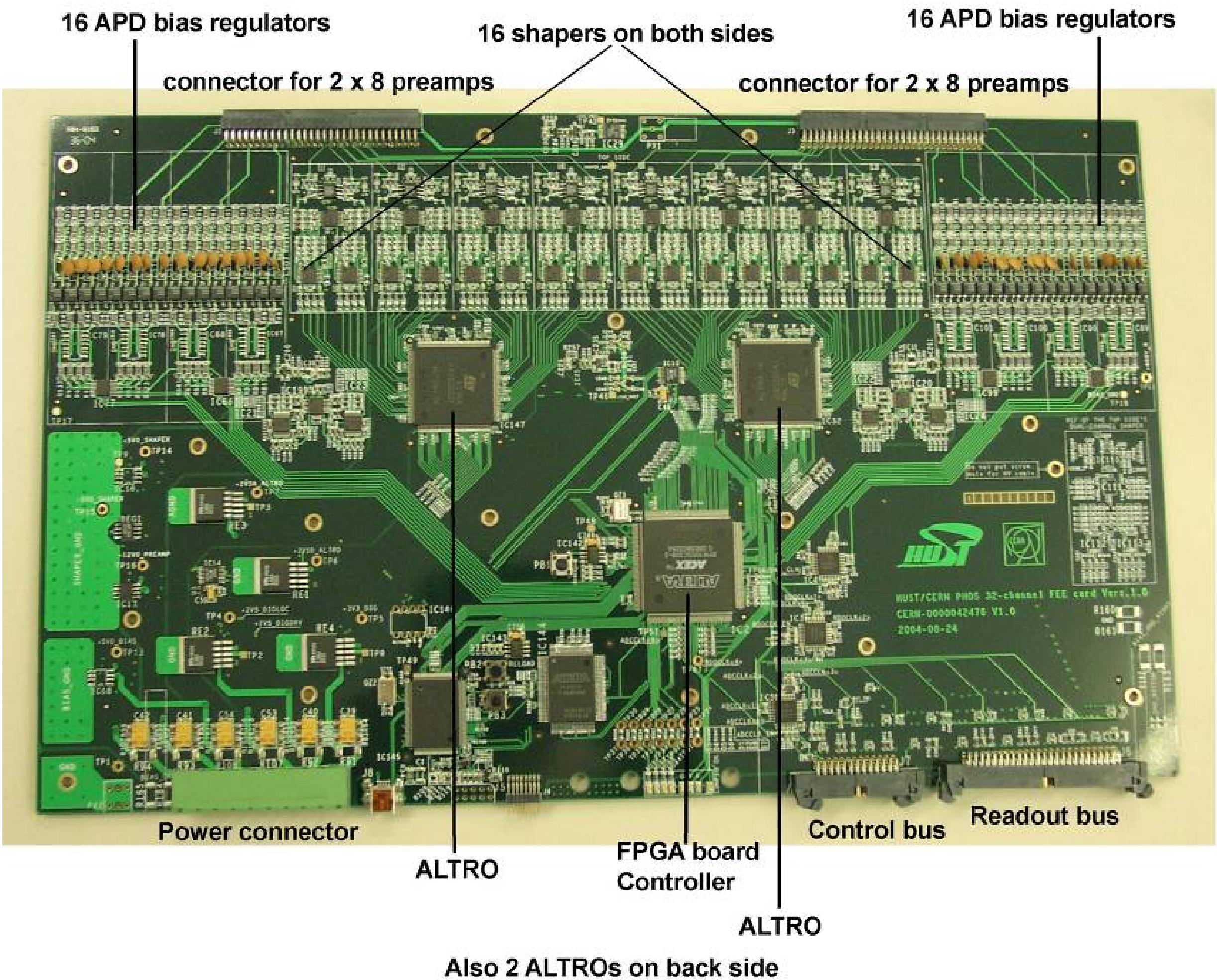


PHOS signal processing scheme



FEE card production

32 channel Front-End Electronics card, V 1.0 Proto, October 2004
Revised version V1.1 has less noise, Mass production in Wuhan end ‘05



FEE card hardware properties

- 32 ch. dual gain shapers $\tau = 1\mu s$
- RMS noise 2 us: 615 e- (3.1 MeV)
- 14 bit dyn range 5 MeV –80 GeV
- 32 APD bias regulators ± 0.1V
- Fast OR (2*2 Xtals) for trigger
- Board controller FPGA (PCM)
- USB controller
- TPC-like readout and control bus
- DAQ and DCS via RCU
- 5.5 Watt, 349 * 210 mm^2

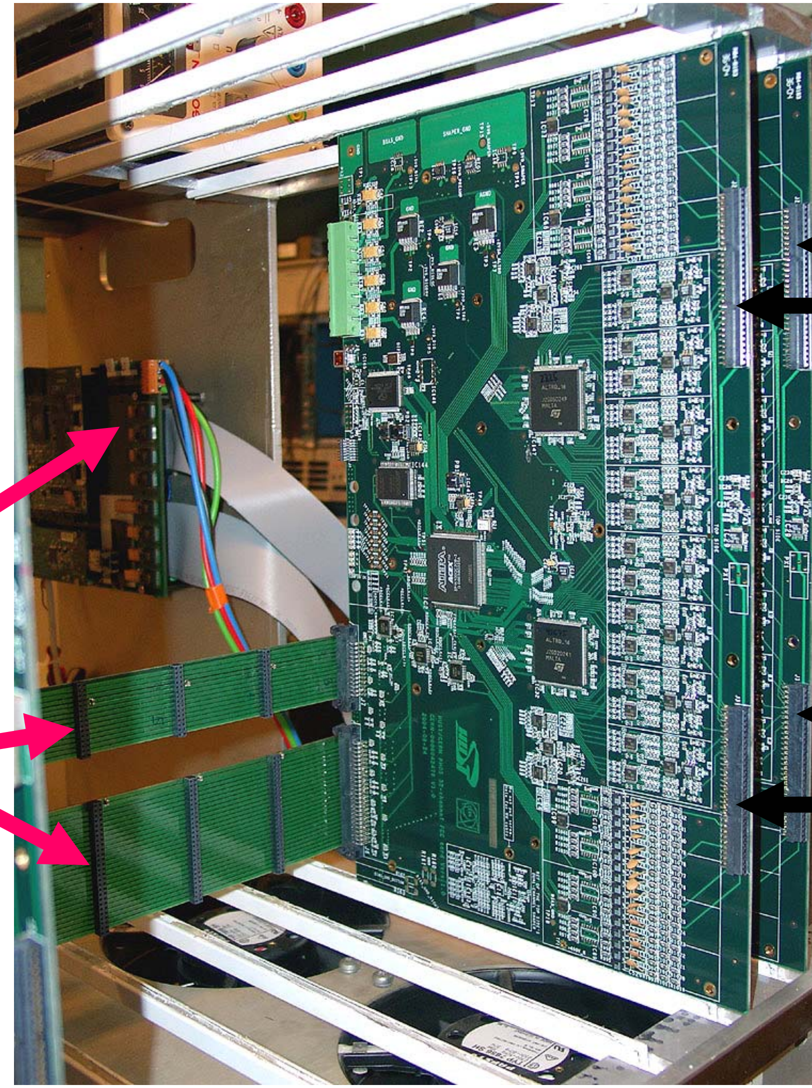
- ✓ R&D CERN April-June 04
- ✓ Cadence Schematics: CERN June 04
- ✓ 10 layer Layout & mounting : Wuhan August/Sept 04
- ✓ Prototypes in Testbeam: October 04
- ✓ Evaluation: CERN Nov-Dec 04
- ✓ Revision: Jan 05
- ✓ Review and final testing: Mai-Sept 05
- ✓ 130 card production Wuhan by end 2005

FEE in lab test

"PHOS" crate

Readout Control Unit (RCU):
bus master for 2*14 FEE cards

GTL readout and control bus
for 14 FEE cards
60 cm PCB strip, 40 cm cable



Connectors to CSP cables

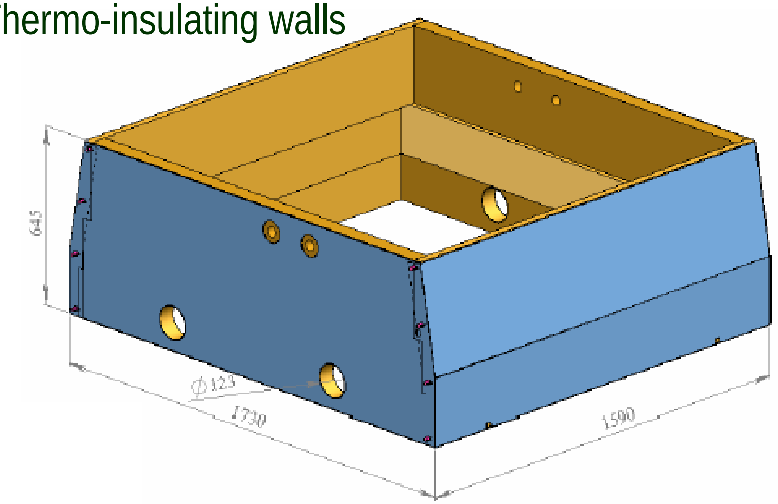
Card spacing and height exactly fits
crystals 2*16 Xtals per FEE card

Status:

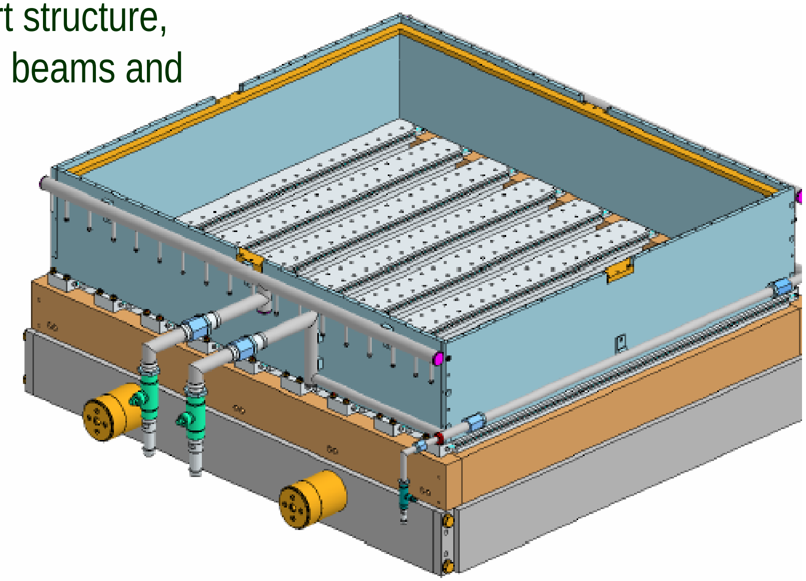
GTL bus production awaited from Norway
24 PHOS RCU's tested by TPC
one Phos crate shipped to Wuhan
Front Connectors and cables all ordered

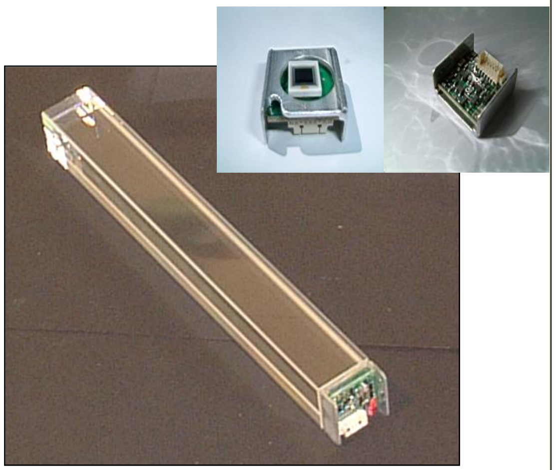
PHOS Support Structure

Thermo-insulating walls



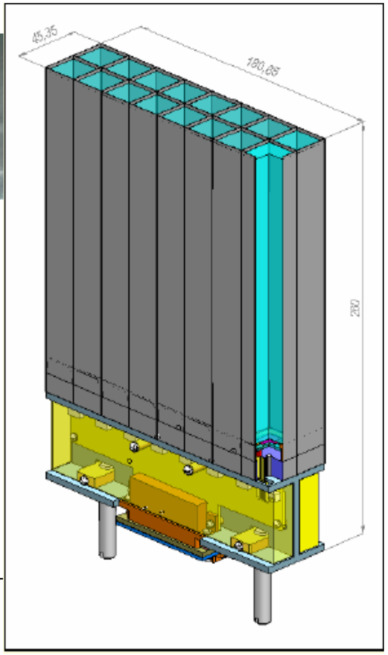
Support structure, cooling beams and panels

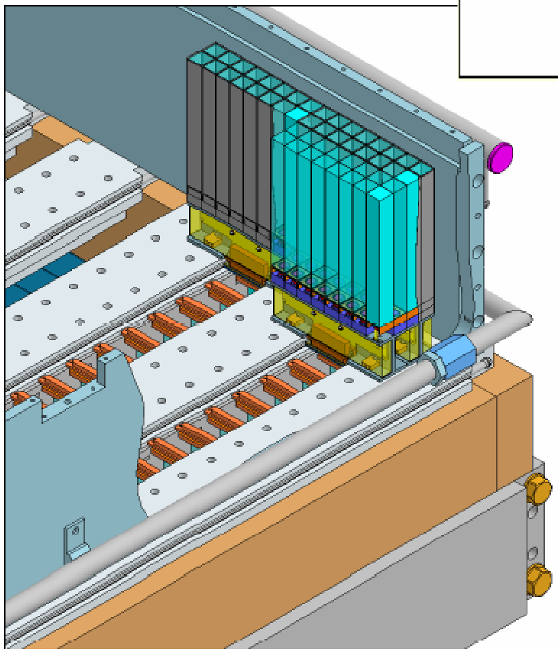




Strip unit

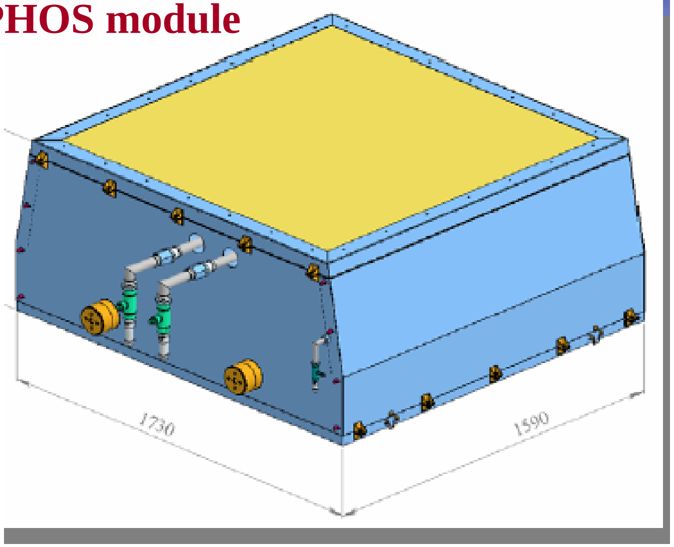
Crystal detector unit





Production of the PHOS module in Russia

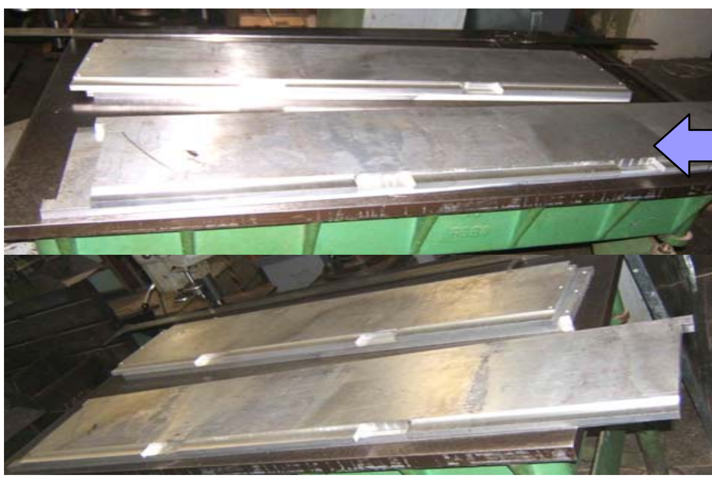
PHOS module

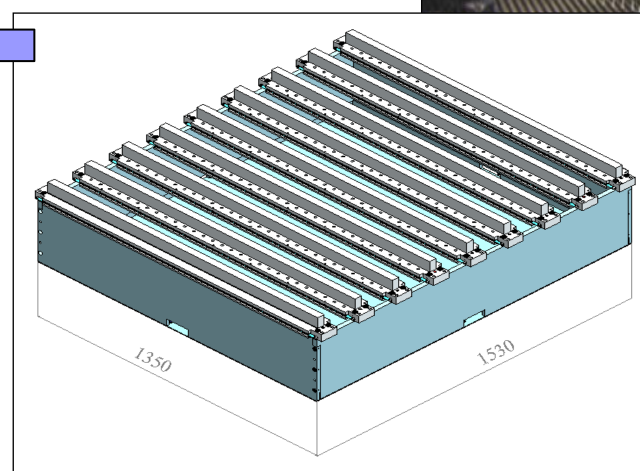


The first module mechanics is under production at METAX Co, Moscow, Russia

November 2004 ⇒ Contract with METAX, Moscow

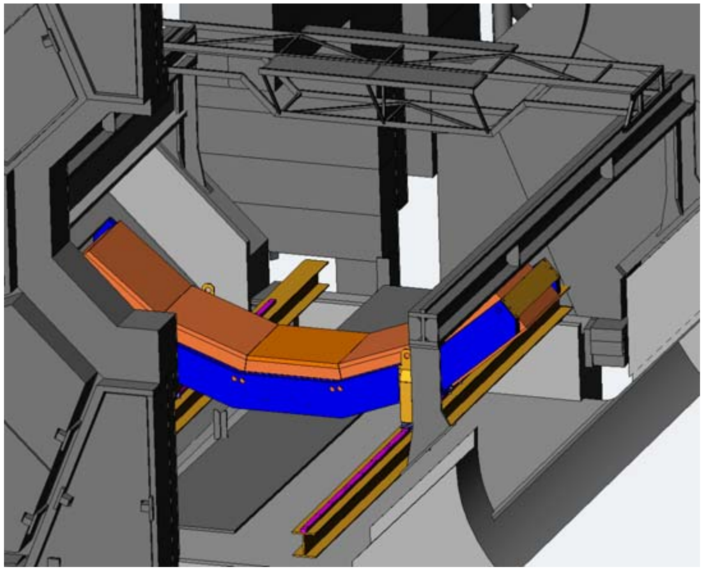
January 2005 ⇒ Production started





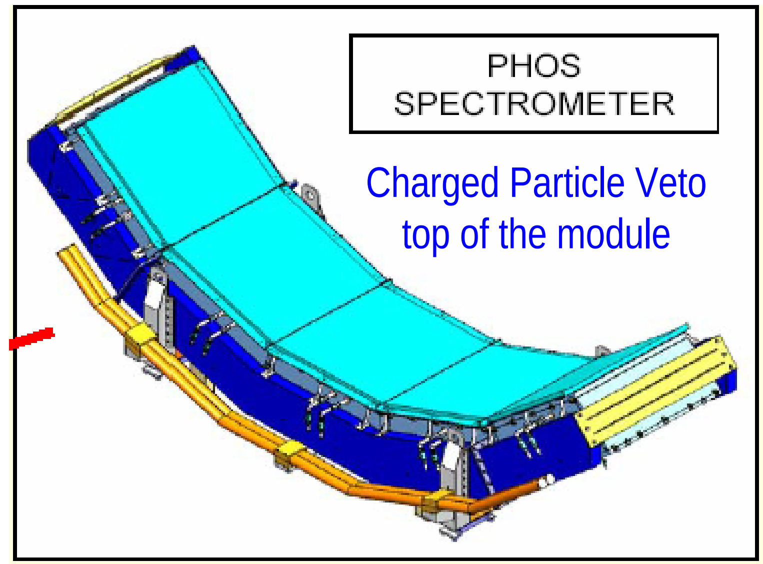
Elements of the cooling panels

PHOS Cradle production in Czech, and **C**harge **P**article **V**eto production in Russia



CPV production in Russia

128×56 cathode pads, anode wires with 5.56 mm pitch.



January 2005 ⇒ All cradle parts produced at TENEZ, the rollers delivered by Hilman Rollers, USA.
February 2005 ⇒ Assembly of the cradle at TENEZ, test
March 2005 ⇒ Disassembly of the cradle at TENEZ.
May 2005 ⇒ Delivery of the parts to CERN
Fall 2005 ⇒ Reassembly of the cradle at CERN.

Performance evaluation with 256ch prototype

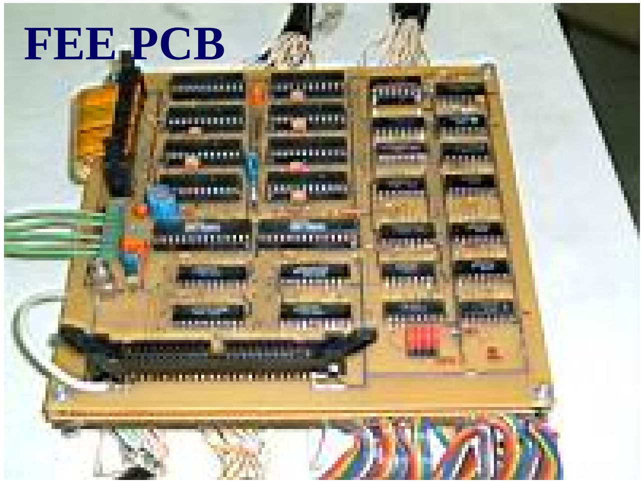


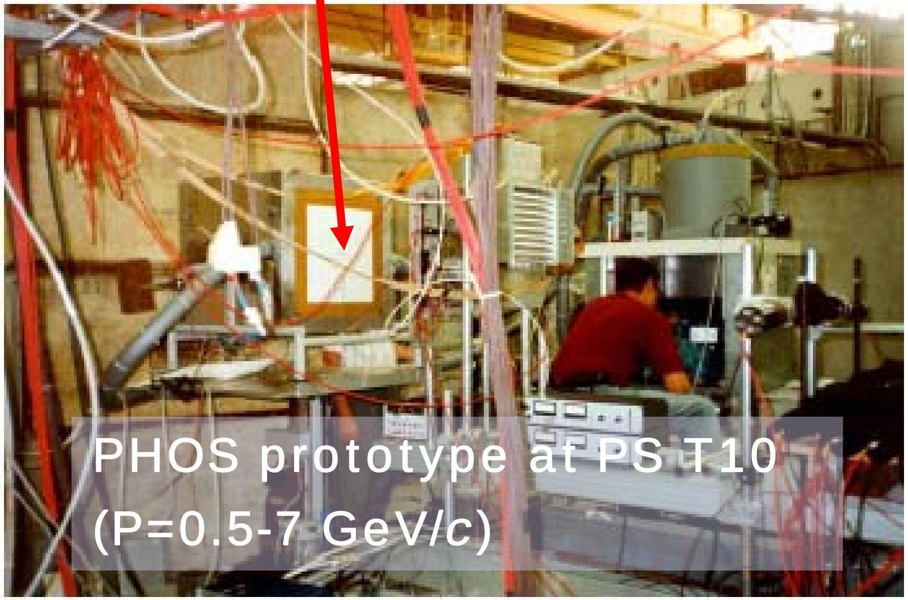



A 256- channels prototype of the PHOS spectrometer assembled at CERN

- Apatity crystals
- Hamamatsu APD's
- Hiroshima preamplifiers
- Kurchatov FEE
- Bergen T-cards
- Sarov mechanics
- Sarov cooling/thermo-stabilization system
- IHEP LED monitoring system
- Oslo DAQ system

PHOS Beam Test in 2004





Timing measurement with the old electronics

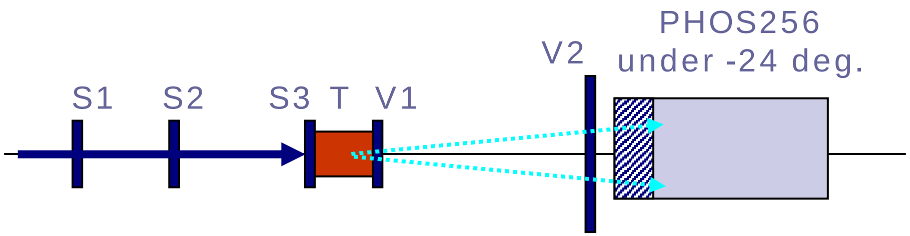
Measurement of electrons and π^0's with the old electronics

Test of the new FEE, based on ALTRO chips
- **-energy resolution**
- **-timing measurement**

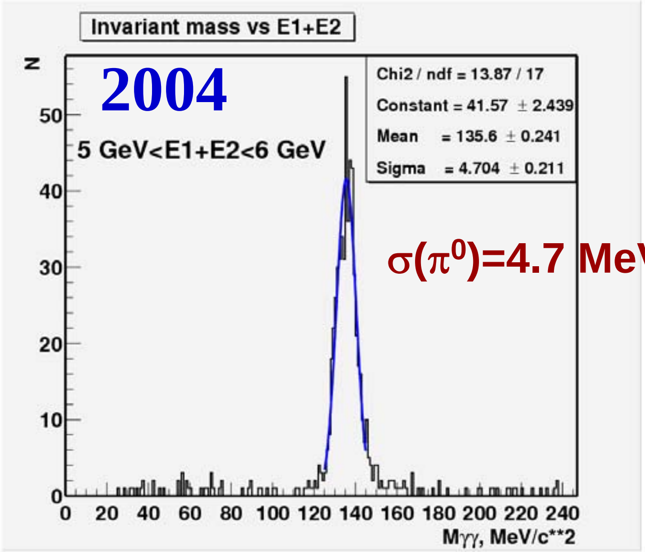
Excellent performances of PHOS256

- Hadron beams at 30 – 70 GeV/*c* on a copper target of 6 cm thickness.
- PWO+APD/CSP (Hiroshima ver.2) with a conventional readout.
- Invariant mass resolution σ_m/m = 7% for π^0, and 3% for η^0 in 2003.
- The mass resolution is improved to be 3.5% for π^0 in the beam test 2004.

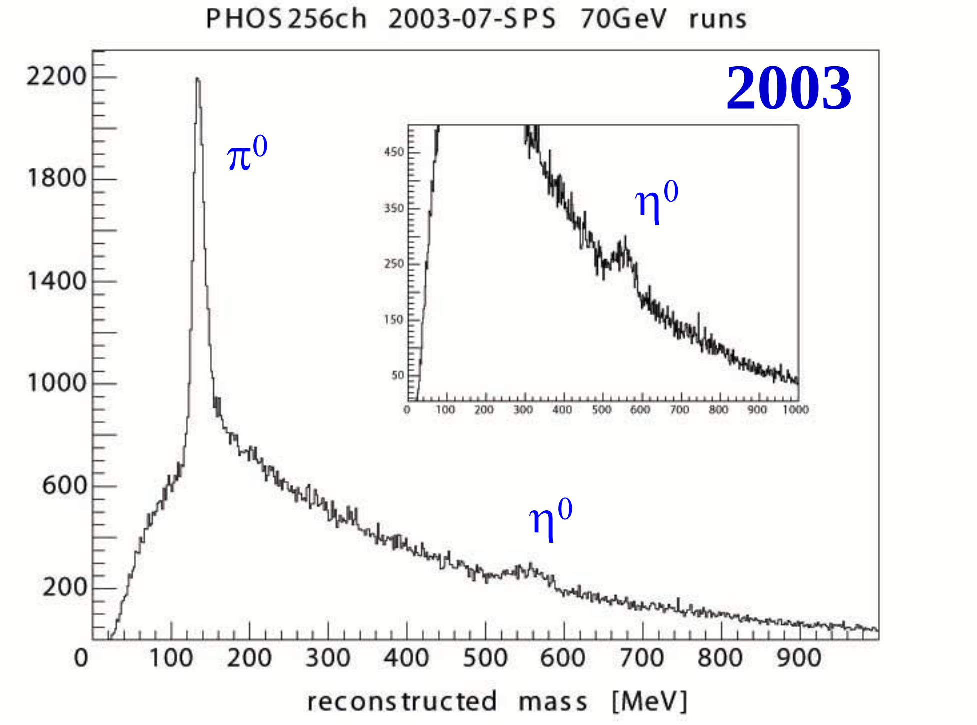
Beam test in 2003



Ref. Log-note, "ALICE PHOS V10"



σ(π⁰)=4.7 MeV

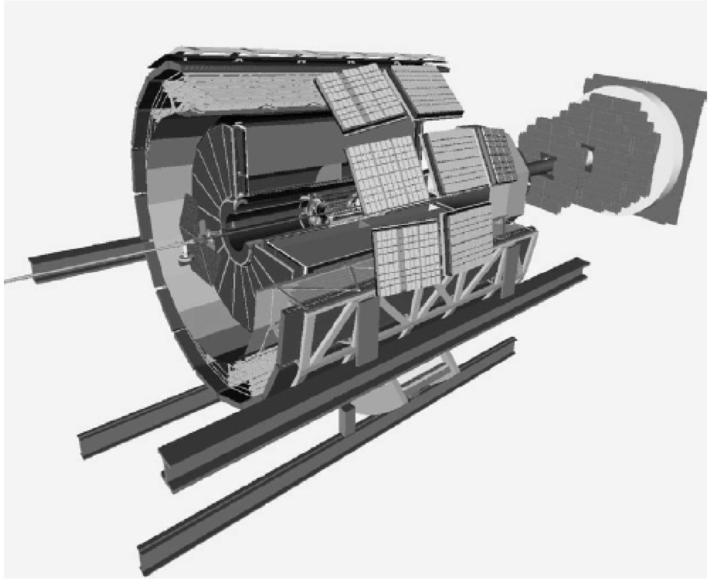


Summary

- The RHIC experiments at BNL looks strongly interacting partonic matter; ***perfect liquid***.
- LHC is another Relativistic Heavy Ion Collider opening a new domain of hard-physics; sensitive to early stage.
- ALICE is a only one dedicated to study such high-energy heavy-ion physics.
- PHOS is a high-granularity, high-resolution electromagnetic calorimeter in ALICE
  - ✓ Lead-tungstate crystal (PWO) with the smallest Moliere radius,
  - ✓ 17,920 crystals in 5 modules, covering $-0.12<\eta<+0.12$ and $\Delta\phi=100$ deg.
  - ✓ APD (Hamamatsu S8148) coupled with low-noise preamplifiers,
  - ✓ readout by 32ch FEE, based on ALTRO chip,
  - ✓ level-0 and -1 trigger capability,
  - ✓ the energy resolution $\sigma_E/E \sim 3 .8\%/\sqrt{E}$ [GeV]
- First module is now being assembled and will be commissioned by the end of 2005.
- FEE mass-production started in Wuhan, and will be delivered in Jan 2006.

Outlook

- Calibration of #1 module in 2006.
- Production of parts for #2 and #3 modules in 2006.
- Calibration of #2 and #3 modules in 2007.
- Production of parts for #4 and #5 in 2007.
- Start physics run in 2007 end.



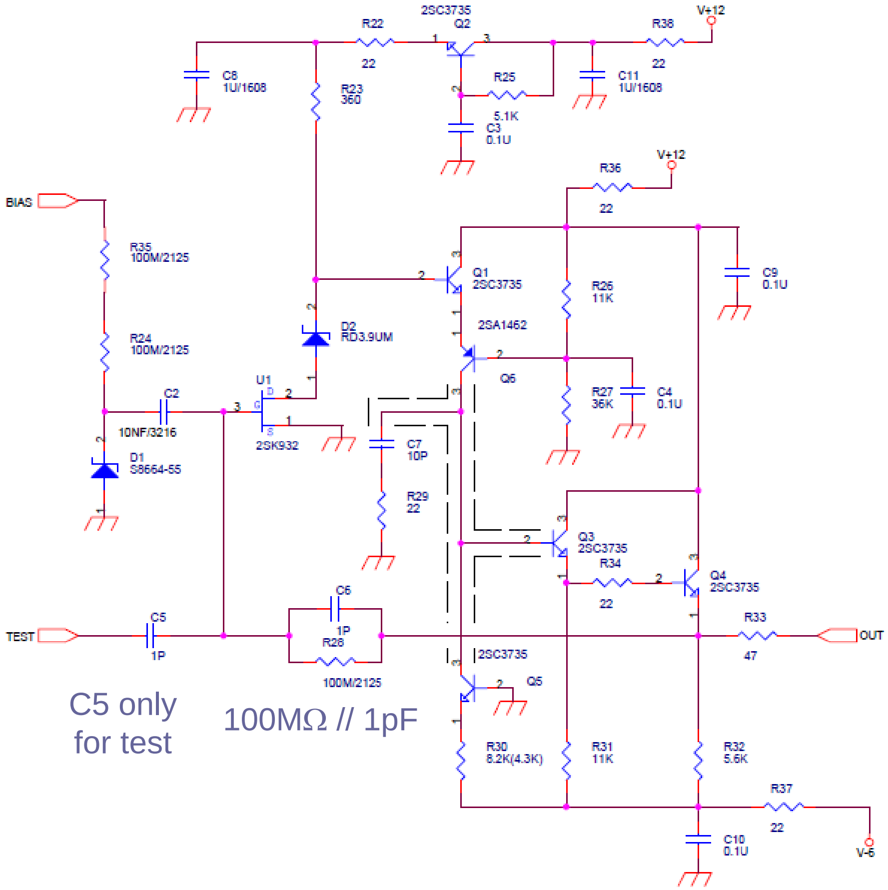
The Experiments at the LHC are getting ready:

A rich harvest of Physics is ahead of us: the LHC is a great place where to do Heavy Ion Physics!

PHOS project-organization

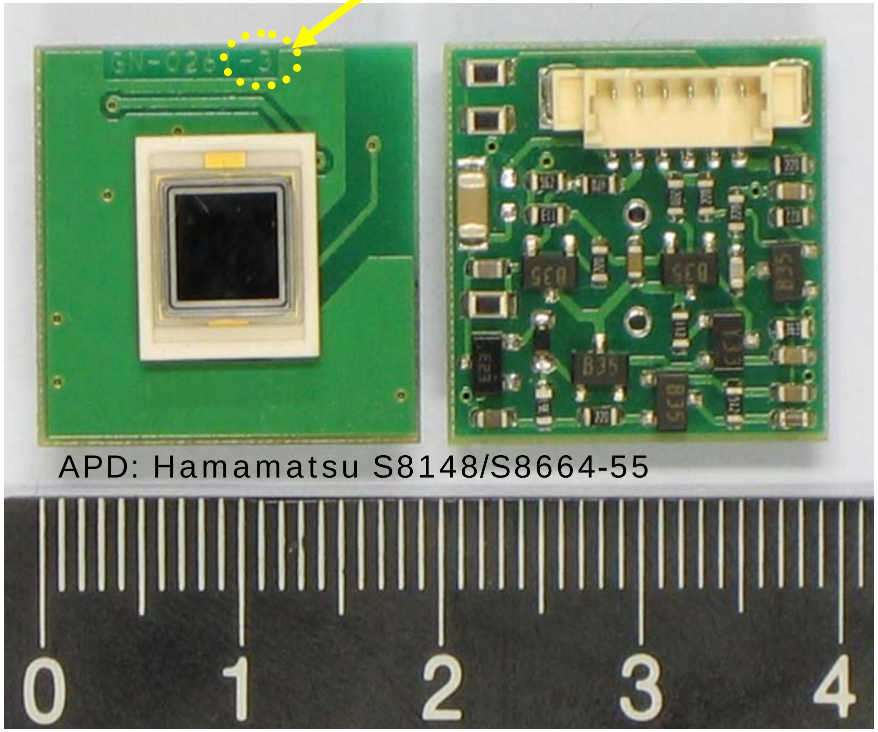
- ✓ China, Beijing, China Institute of Atomic Energy
- ✓ China, Wuhan, Central China Normal University
- ✓ China, Wuhan, Central China University of Science and Technology
- ✓ Czech Republic, Prague, Academy of Science of the Czech Republic, Institute of Physics
- ✓ Germany, Münster, Westfälische Wilhelms Universität, Institute für Kernphysik
- ✓ France, Nantes, Laboratoire de Physique Subatomic et des Technologies Associées
- ✓ Japan, Hiroshima, Hiroshima University
- ✓ Norway, Bergen, University of Bergen, Department of Physics
- ✓ Norway, Oslo, University of Oslo, Department of Physics
- ✓ Poland, Warsaw, Soltan Institute for Nuclear Studies
- ✓ Russia, Moscow, Russian Research Center ‘Kurchatov Institute’
- ✓ Russia, Protvino, Institute for High Energy Physics
- ✓ Russia, Sarov, Russian Federal Nuclear Center ‘VNIIEF’
- ✓ Russia, Dubna, Joint Institute for Nuclear Research
- ✓ Switzerland, Geneva, CERN

Backup Slides



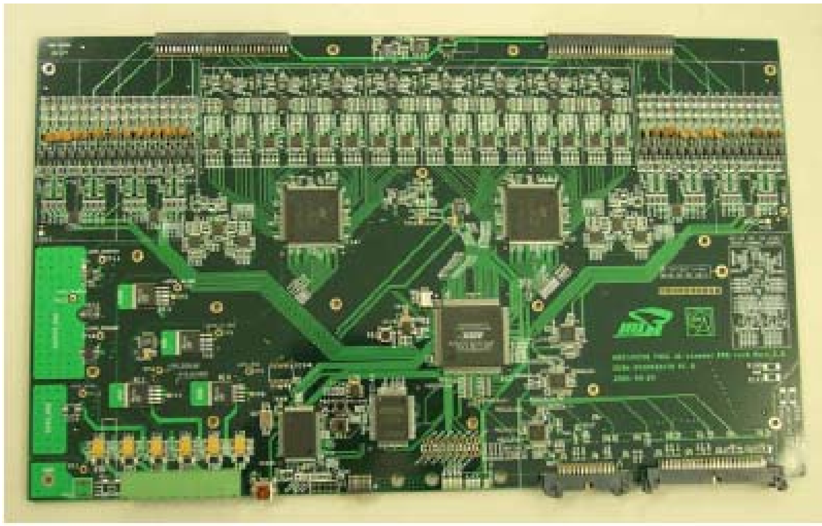
APD preamplifier:

- Originally designed and built at ***Bergen***.
- Re-designed in 2002 at ***Hiroshima*** using components available in Japan.
- Hiroshima ver.2 is successfully performed in PHOS256 in 2003/04.
- Minor modification for ver.3 in 2004.
- 5,000 of Hiroshima ver.3 has been produced for the first module.



J-FET	2SK932 (I_{DSS} rank =23) by *SANYO*
Sensitivity	0.833V/pC
Rise time	15-20 ns over full range
Noise (ENC)	200 e + 3.2 e /pF x C_{in}(pF)
Output polarity	Positive
Feedback loop	100MΩ // 1pF
Power dissipation	64mW (4.2mA @12V & 2.2mA @-6V)

PHOS読み出し試作機(32ch)



10 layer PCB, 2mmt, 35x21 cm^2
32 channels high and low gain
32 channels APD bias controllers
4 ALTRO's with GTL readout backend
Board Controller with USB port

STマイクロエレクトロニクス ALTROチップ

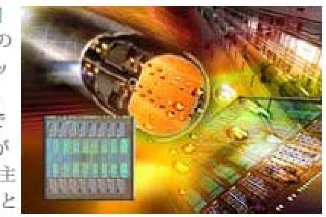
STニュース | 広告 | 製品情報 | イベント | 環境・品質 | 会社案内 | 採用情報 | お問い合わせ

STニュース

T1252G 2002年11月25日

STは欧州原子核研究機構CERNのALICEプロジェクトチームと共同で
世界で最先端のデータ取得システム用SoCを開発

重要な科学研究プロジェクトの成功が宇宙/医療/産業向けアプリケーションの利益に貢献



STマイクロエレクトロニクス(NYSE: STM、以下ST)は、科学実験用に設計された非常に複雑なシステム・オン・チップ(SoC)デバイスの生産を開始したことを発表しました。ALTROと呼ばれるこの新チップは、STが、ALICE Collaborationと共同で開発していたものです。ALICE Collaborationは、大学と研究機関から組織されたグループであり、スイスのジュネーブ近郊にあるCERN(欧州原子核研究機構)が現在建設中のLHC(大型ハドロン衝突型加速器)を使用して行われる主要実験の1つに向けて準備を進めています。世界最大の粒子加速器となるLHCによって、40ヶ国を超える様々な国の科学者が粒子構造とその性質を研究するために、多くの重要な実験を行うことができるようになります。

このALTROチップは、16個の低出力ADC(アナログ・デジタル・コンバータ)とトランジスタを600万個以上搭載したデジタル処理用カスタム回路と800Kbitsのデータメモリを集積したチップで、2007年に開始されるALICE(A Large Ion Collider Experiment重イオン衝突実験)と呼ばれる重要な実験に使用される予定です。ALICEの実験には、様々なタイプの重イオンで起こる高エネルギー衝突の実験がふくまれています。さらに、1つの衝突によって生成される何万もの粒子について研究するために、ALICE Collaborationでは、個々の電子の存在を検出することができる約60万個の小型センサを搭載した高性能検出器(TPC：Time Projection Chamber)を開発中です。各センサからの信号の増幅、デジタル変換、さらにTPCと共に地中深くに設置された前段処理用電子装置による前処理が必須となります。

- 16 channels per chip
- 16 mW / channel @ 10 MS/s
- 9.7 ADC Effective Bits @ 10 MS/s
- analogue differential inputs
- self-adaptive baseline correction
- 800 Kbit internal memory
- SEU-proof redundant control
- 300 MB/s readout speed
- Up to 40 MS/s sampling rate
- STM 0.25 μm HCMOS-7 process
- 6 million transistors
- 8.3 × 7.7 mm die size
- 64 mm^2 die area (50% ADCs)
- 2.5 V supply for logic and ADCs
- TQFP-176 packaging

Silicon avalanche photo diode (APD)

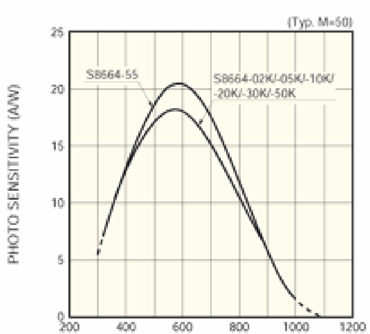
HAMAMATSU

Part Number	Type	Package	Active area diameter or length [mm]
S8664-55	Si APD	Ceramic	5

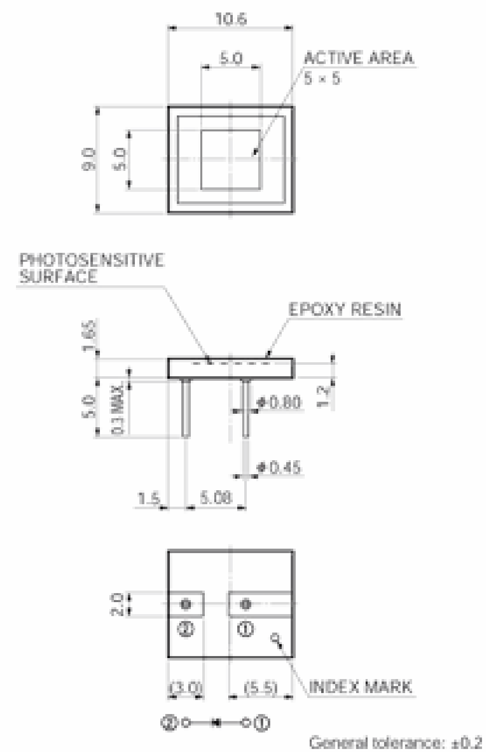
APD optimized for UV to Visible light Low capacitance type + Ceramic package

Key Specifications

Part Number	S8664-55
Package	Ceramic
Active area diameter or length	5mm
Active area height	5mm
Wavelength Min.	320nm
Wavelength Max.	1000nm
Peak wavelength	600nm
Photo sensitivity	0.24A/W at peak
Dark current Max.	50nA
Cut-off frequency	40MHz
Terminal capacitance	80pF



Drawing



Click image to enlarge

PWO結晶及びAPD素子の静的特性

- Comparison of PWO's produced by;
  - Furukawa, Japan
  - RI&NC in Minsk, Belarus
  - North Crystal in Apatity, Russia

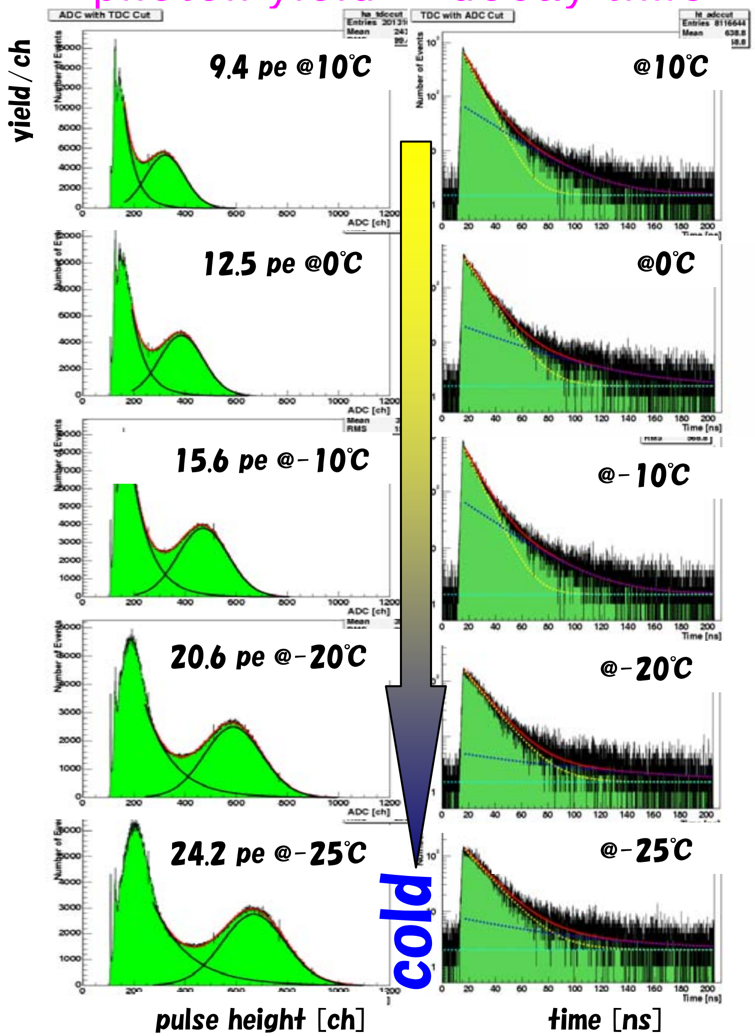
  on;
  - photon yield and
  - decay time

  as a function of temp, and
- APD as a function of;
  - Temperature and
  - HV

Y-doped $PbWO_4$

Density 8.28 [g/cm^3]
Radiation length 0.89 [cm]
Moliere radius 2.2 [cm]
Peak emission 420~440 [ns]
Refractive index 2.3

NC PWO w/pmt for ^{60}Co-γ's



Experimental conditions @ LHC

- Commissioning start April 2007
- Initial few years **(1HI 'year' = 10^6 effective s, ~like at SPS)**
  - **2 - 3 years Pb-Pb** **L ~ 10^{27} cm^{-2}s^{-1}**
  - **1 year p - Pb 'like'** (**p**, d or α) **L ~ 10^{29} cm^{-2}s^{-1}**
  - **1 year light ions** (eg Ar-Ar) **L ~ few 10^{27} to 10^{29} cm^{-2}s^{-1}** plus, for ALICE (limited by pileup in TPC):
  - **reg. pp** run at $\sqrt{s}$ = 14 TeV **L ~ 10^{29} and < 3×10^{30} cm^{-2}s^{-1}**
- Later:
  - different options depending on Physics results